Human Engineering Process

DD 21/ONR

SC-21 S&T Manning Affordability Initiative

HUMAN ENGINEERING PROCESS

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Disclaimer

This information constitutes a living document, and as such it is subject to change. It is believed that the overall, global process outlined here is valid. The details and descriptions of sub-steps of the process and supporting tools, however, may change over the course of the SC-21 S&T Manning Affordability Initiative. The initiative is focusing on developing systems to support operators and designers, and lessons learned will continually be assessed and reflected in this document.

Process Overview

> Human Engineering: The application of human performance principles, models, measurements, and techniques to systems design. The goal of human engineering is to optimize systems performance by taking human physical and cognitive capabilities and limitations into consideration during design.
>
> DoD Directive 5000.53 (1988)

This document presents an overview of the human engineering process defined as part of the SC-21 S&T Manning Affordability Initiative (S&T). This process was created with two goals, the first of which was to define a generalizable process for human engineering that is compatible with systems engineering practices. The second goal was to define a process that can be used as a roadmap for identifying and (where required) developing tools and capabilities for the S&T project's Human-Centered Design Environment (HCDE).

As shown in Figure 1, the human engineering (HE) process is broken into six high-level steps – Mission Analysis, Requirements Analysis, Function Analysis, Function Allocation, Design, and Verification. The division of this process into different steps was based on pre-existing cycles of iteration and definable transitional products. The process is designed to be applied throughout the system development life cycle (concept definition, system design, subsystem design); the nature and detail of the activities performed in the process will therefore change as a function of the current life cycle step. The process is also intended to be iterative in nature and support concurrent design paths. A continual pattern of trade-off analysis and evaluation has been included.

Some of these sub-steps are specific to human engineering, but others are more general in nature and may cross into other disciplines or may be seen as system engineering process steps. Steps in this latter category may not even be performed by human engineers or with the intent to "do" human engineering, but their outputs typically include information or other products that drive decisions or are otherwise needed within the human engineering discipline.

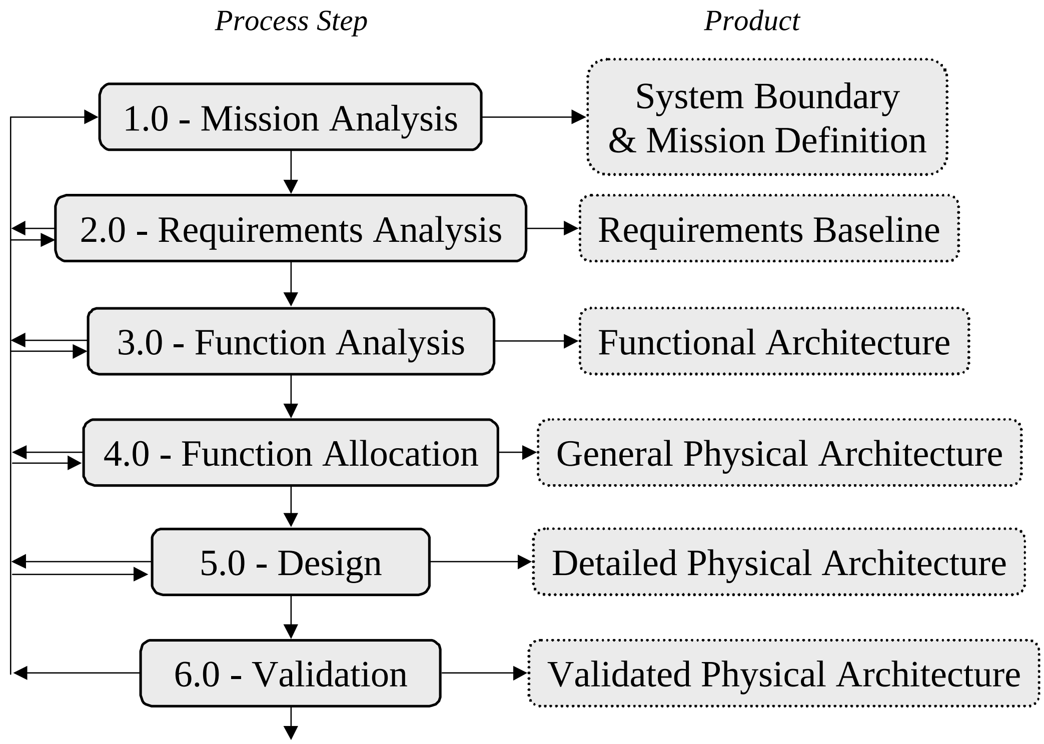

Figure 1. Top-Level Diagram of Human Engineering Process.

1.0 – Mission Analysis
Determine overall purposes or objectives and capabilities of the system and the environment in which the system must operate. Determine what basic functions the system is intended to perform. Identify or create mission scenarios. Focus in this stage is on the definition of the system boundaries, treating the system as a “black box” and defining inputs, outputs, environment, and other constraints.

2.0 – Requirements Analysis
Identify the characteristics of the system necessary to meet mission requirements. Determine the intended users (and maintainers) of the system. Identify and define the activity-related needs of users. Assess the feasibility and internal compatibility of the system requirements. Define the system’s measures of effectiveness and measure of performance and the mission, human, and job/task requirements. Define the Human Role Strategy and manning, training, and cost guidelines.

3.0 – Function Analysis
Define the system’s functional architecture – the sequence of operations or events to turn inputs into desired outputs – and compare the potential alternatives. Although the system may be broken into functions, tasks, and subtasks to be performed, no allocation to particular system components takes place. This stage and the three following stages may be initially performed at a high system level with little function decomposition, but these stages must be reiterated at a level of greater detail as the design progresses.

4.0 – Function Allocation

Distribute the defined functions between available resources (humans, hardware, software or combinations). The allocation of some functions will be mandatory and predetermined by constraints established in the Mission Analysis or Requirements Analysis stages of design. Allocation should also be determined by comparison of performance between humans, hardware, and software; cost factors; and affective and cognitive support for the operators. Allocation decisions should be made so as to maximize total system performance and effectiveness. Allocation of a function may require redefinition of its component subfunctions. Function allocation will also be guided by what pieces of information and decisions are required to initiate, sustain, and otherwise support the functions. The designer must determine how decisions affect or alter the system performance of the system itself. Allocation may be done in static terms or it may be dynamic, with functions changing their allocation at different stages of the system. The system must be defined in terms of component functions, tasks, and subtasks, including the flow of information and the allocation of the functions, tasks, and subtasks to individual system components.

4.1 – Mandatory Function Allocations

The first functions and decisions to be allocated must be those having specific allocations mandated by system requirements, the Human Role Strategy, or other factors. The Human Role Strategy will require that some functions or decisions be performed or made by humans within the system. Some functions or decisions will be required to be performed or made by hardware or software components of the system or by humans with the assistance of other system components in order to meet system requirements. The allocation of these functions and decisions may then logically require that other functions or decisions be allocated to a specific portion of the system.

4.2 – Create Alternate Allocations of Remaining Functions

Identify potential allocations for functions not yet allocated. Begin by assessing the capabilities and limitations of hardware and software technology as well as humans. Allocations may be made to hardware, software, humans, or combinations. Allocation may be static or dynamic, changing with operational conditions, workloads, or mission priorities. Allocation of mission-critical functions during the primary mission phase should take priority, followed by other primary mission functions and functions from other mission phases. Allocation options should be made based on component and system performance and a variety of other criteria.

4.3 – Select Optimal Function Allocation

Based on a qualitative comparison of system design factors (SDFs), select an optimal allocation of functions from the candidate allocations.

4.4 – Verify Allocation Compliance with System Requirements

Compare the selected allocation of functions to the system requirements, including mission requirements, human requirements, job/task requirements, and other MOE's and MOP's.

5.0 – Design

Define a time-based description of the allocated functional architecture of the system. Particular attention must be paid to interactions between tasks and between humans and equipment and the flow of information and objects between components of the system as currently allocated. Analyze this architecture and redefine functions and tasks as necessary to meet mission requirements. Determine whether or not the specified levels of activity (physical, mental, etc.) of both humans and equipment can be met with the resources currently available (or projected to be available). Once the functional architecture meets mission and system requirements, operator interfaces may be specified and designed. Changes made to the functional architecture at this stage will require a return to earlier stages to ensure that all system/mission requirements will be met.

5.1 – Task Design and Analysis

Based on the functions allocated to humans, develop the human tasks required to ensure successful completion of the function. Task development is based on a decision analysis approach. This produces a depiction of the task in terms of the cues to alert the human that a decision/action needs to be taken, the decisions/action to be made, the information required to support the decision, and mechanisms to implement the results of the decision/action. The critical characteristics and interactions are also articulated.

5.2 – Design Human Interfaces

Design the interfaces between humans and hardware, software, and other humans. Both physical and procedural interfaces should be considered. Develop individual and team interfaces.

5.3 – Estimate Performance, Workload, and Manning Levels

Estimate the physical (perceptual, psychomotor, physiological, etc.) and cognitive workload levels of individuals and teams within the system. Define workload stressors and their effects on human performance, operator coping strategies, and the effects of task neglect / delay. Workload and the resultant manning and training requirements are to be optimized to meet required performance levels.

6.0 – Verification

Assess the potential performance of the system with respect to its ability to achieve its required levels of operation (MOE's, MOP's). Verification may be carried out either during conceptual stages using analytical or executable system models or after a physical prototype or mock-up has been constructed using human-in-the-loop simulations. Verification of some system components may be concurrent with design of other components. Verification is performed within the context of design, not production. If the system under design is unable to achieve the required levels of performance and operation, then either the requirements must be altered or the design must be improved through re-allocation of functions or selection of an alternate design.

Human Engineering and Systems Engineering

Traditional problems in human engineering and the application of human factors principles in general have included lack of compatibility with an overall systems engineering process and the lack of readily observable inputs to the overall design process.

One of the causes of these traditional problems has been a difference in terminology between the systems engineering and human engineering disciplines. When possible, this process uses terminology equivalent with that found in the systems engineering domain and provides definitions of human engineering terms that may not be familiar to those with a systems engineering background. It is hoped that the use of terminology common to the systems engineer coupled with definitions of key human engineering terms will enable the systems engineer to visualize how human engineering fits within an overall systems view. It is also hoped that it will enable the human engineer to see how human engineering and human factors principles and products interact with systems engineering.

The human engineering process presented here was designed to be compatible with the process outlined in IEEE 1220, Standard for the Application and Management of the Systems Engineering Process. The two processes have a shared terminology, and the steps of the processes themselves have been designed to be parallel, as shown in Figure 2. The green blocks represent portions of the systems engineering process, and the yellow blocks designate the human engineering activities that take place within systems engineering.

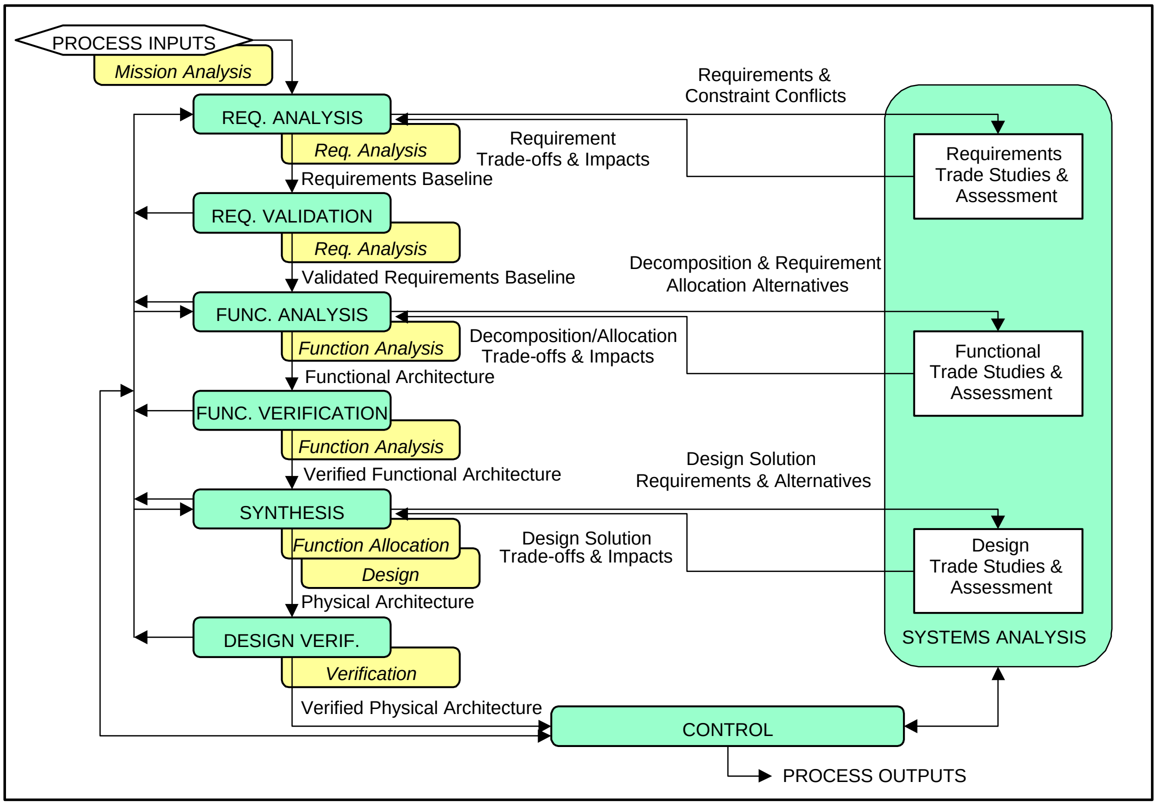

Figure 2. Comparison of Human Engineering with Systems Engineering Process of IEEE 1220.

1.0 – Mission Analysis

DEFINITION: Determine overall purposes or objectives and capabilities of the system and the circumstances and environment in which the system must operate. Determine what basic functions the system is intended to perform. Identify or create mission scenarios. Focus in this stage is on the definition of the system boundaries, treating the system as a "black box" and defining inputs, outputs, environment, and other constraints.

1.1 Identify Mission Objective/Needs: Determine what the proposed system is supposed to accomplish, or determine the threat that must be addressed. Determine why the system is needed. This may be defined as a gap in current capabilities that must be filled or a current system that needs to be replaced or upgraded.

1.2 Define System Boundaries: Determine what elements are subject to design and what elements are not. Determine what the inputs and outputs (including personnel and informational and physical elements) of the system will be. The system boundaries may change as the design of the system progresses.

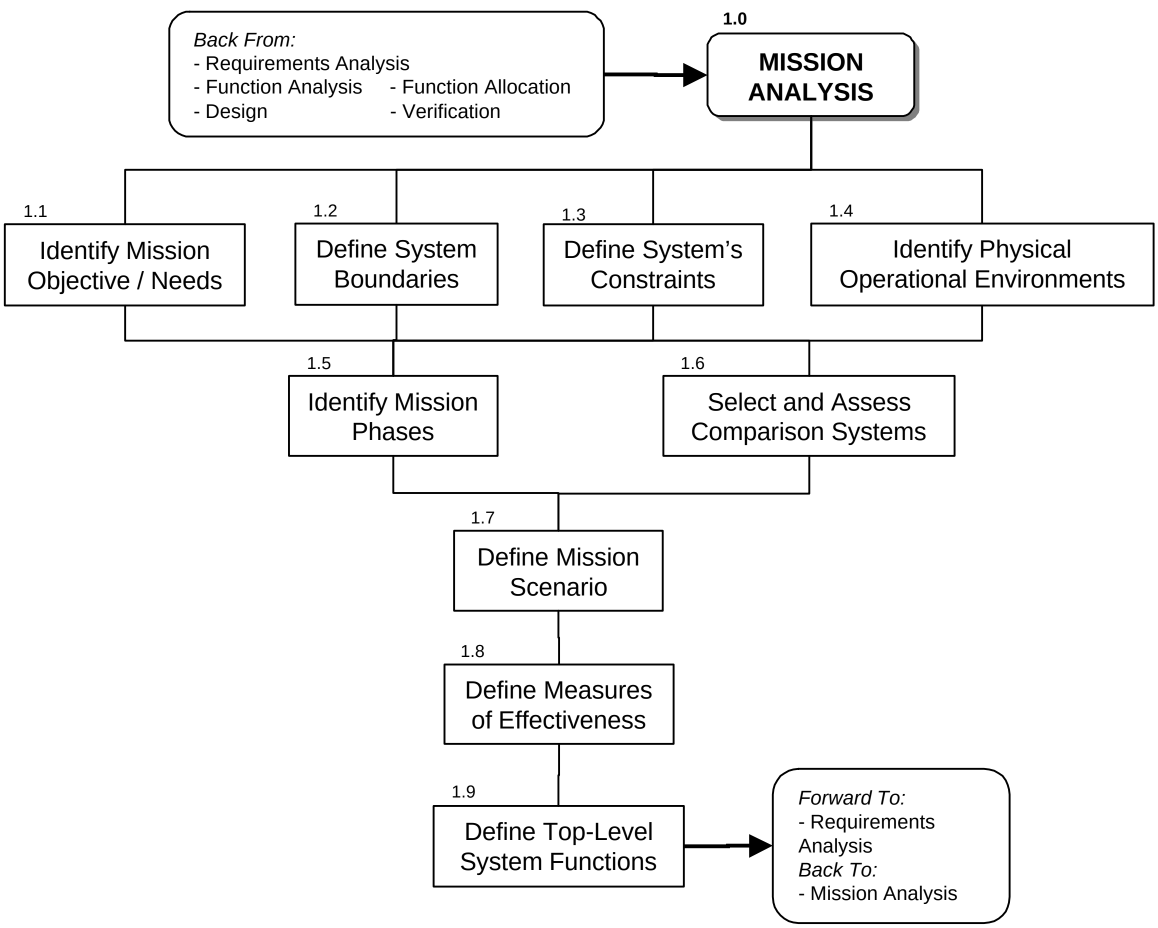

Figure 3. Mission Analysis Process Diagram.

1.3 Define System's Constraints: Given the definition of the system boundaries, determine what constraints are placed on the system by external factors. Constraints include cost and funding (for design as well as operation and maintenance), infrastructure, training constraints, manning availability, etc. How constraints will change over time (through both life cycle phases and operational phases) must be identified.

1.4 Identify Physical Operational Environments: Determine the environments in which the system will operate. Both current and future or anticipated environments must be considered. The physical environment will impact system components such as life support, lighting, vibration and noise control, operator exposure or duty limits, and human performance shaping factors.

1.5 Identify Mission Phases: Define changes in the system mission throughout individual missions and the system’s life-cycle. This includes identification of modes of operation and identification of the threat for which the system is being designed will change over time.

1.6 Select and Assess Comparison Systems: Select previously designed or built systems or subsystems for comparison with the system under design. Comparison systems (or subsystems) should have objectives or purposes similar to that of the system being designed. The system under design may have multiple comparison systems or a variety of comparison subsystems from different pre-existing systems. Assess the potential comparison systems for their similarity and applicability to the system under design.

1.7 Define Mission Scenarios: Describe the events of the system mission (or missions) in detail, including identification of mission phases, mission time scale, and events external to the system. Complete descriptions of a range of missions from the typical, representative mission to worst-case missions. Scenarios may be in narrative or graphic format. Graphic formats include plots of system activities, functions, and events against time or location.

1.8 Define Measures of Effectiveness: Define the metrics by which the overall effectiveness of the system will be assessed. Measures of effectiveness (MOEs) may be based on overall system performance, component performance, or on performance during particular mission phases. The relative weights or importances of MOEs may be defined at this point.

1.9 Define Top-Level System Functions: Define the basic functions that will be necessary for the system to meet the mission objective or need.

2.0 – Requirements Analysis

DEFINITION: Identify the characteristics of the system necessary to meet mission requirements. Determine the intended users (and maintainers) of the system. Identify and define the activity-related needs of users. Assess the feasibility and internal compatibility of the system requirements. Define the system's measures of performance and the mission, human, and job/task requirements. Define the Human Role Strategy and manning, training, and cost guidelines.

2.1 Identify Functional Requirements: Identify and articulate the activities, tasks, or actions required to achieve the stated system mission.

2.2 Identify Performance Requirements: Identify and articulate the performance capabilities required to successfully meet the stated system mission.

2.3 Define Measures of Performance: Define the metrics by which the performance of the system will be assessed. Measures of performance (MOPs) are defined to a greater amount of specificity than measures of effectiveness.

2.4 Define Human Role Strategy: Determine what decisions and activities within the operation of the system are required to be performed by humans or are not allowed to be performed by humans. This defines the intended balance between automation technology and human control. Examples include leaving critical decisions in the operator's control and mandates that potentially labor-intensive actions be performed by automation. Also included may be estimates of acceptable staffing levels and costs, anticipated levels of skill and training, appropriate number of people that will be needed, and whether the operators and maintainers will be local or remote from the mission equipment. Potential human roles in the system include operator, maintainer, sensor, manager, supervisor, analyzer, decision maker, information manager, backup to equipment, or any mix of such roles. Alternative Human Role Strategies may be developed for later comparison. The Human Role Strategy will be used to guide the allocation of functions.

2.5 Identify Required Infrastructure: Based on the definition of the system boundaries, identify the infrastructure that must be created or maintained to support the system. Infrastructure includes items that may not typically be considered to be part of the system, such as supply networks, transportation, and logistics issues.

2.6 Identify Interfaces with Other Systems: Based on the definition of the system boundaries, identify other systems (current and anticipated) with which the system under design will interact and characterize these interfaces. Differences between legacy systems, future systems, and the system under design must be identified.

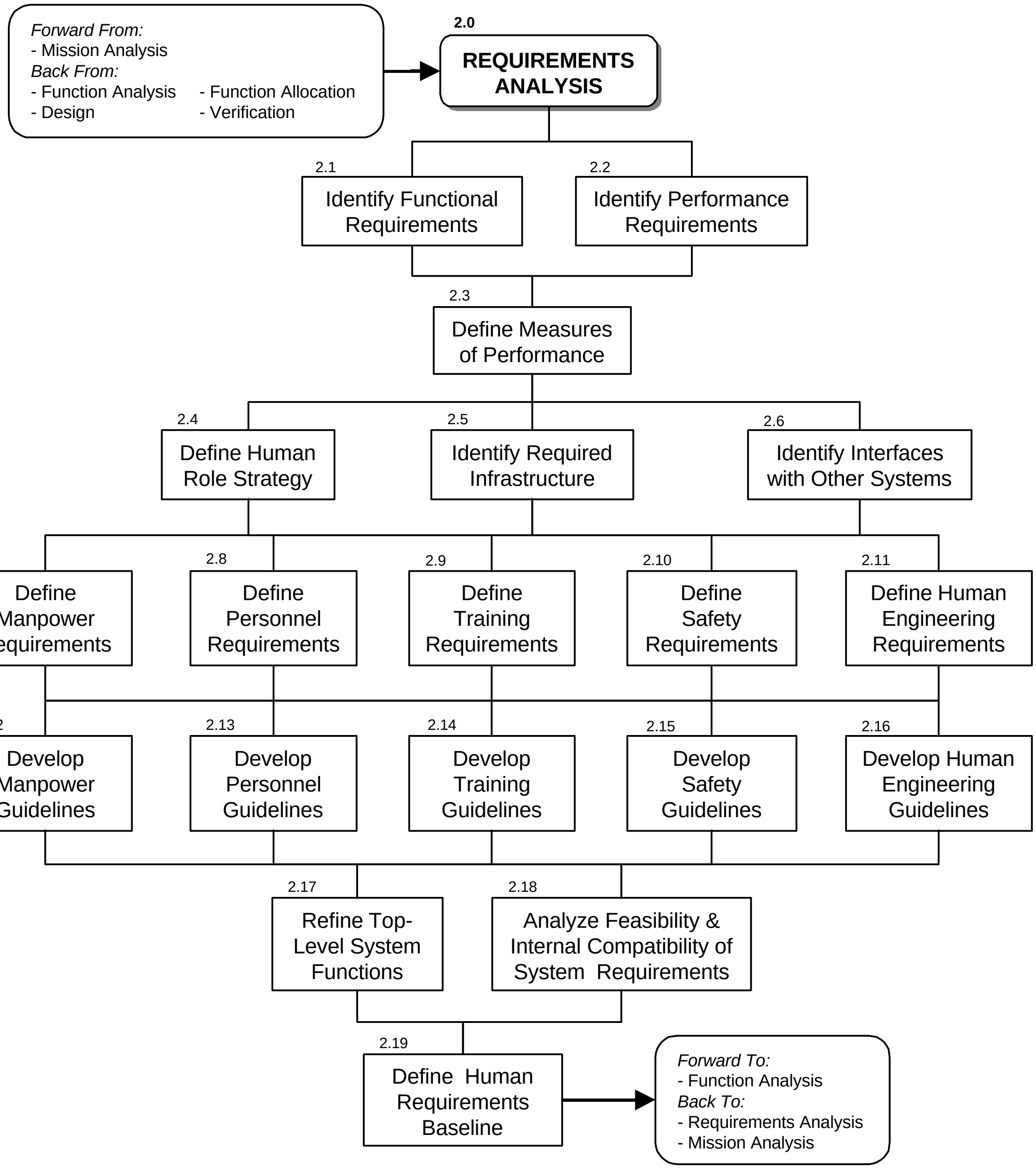

Figure 4. Requirements Analysis Process Diagram.

2.7 Define Manpower Requirements: Define the billets needed to operate, maintain and support all system elements across the required operating capabilities in the projected operational environment. Determine the number and mix of military, DoD civilian and contractor personnel who operate, maintain, support and provide training for the systems.

2.8 Define Personnel Requirements: Define the qualitative attributes of the manpower requirements. Personnel factors include the abilities, skill levels, experience, Navy rating structures, physical constraints and force management policies (e.g. recruitment and retention) needed to execute the required tasks.

2.9 Define Training Requirements: Define the required instruction and applied exercises, to include measurable and specific performance level, for acquiring and retaining knowledge, skills and abilities (KSAs) necessary to prepare personnel to operate, maintain and support all system components in the required operational environment throughout the system life cycle.

2.10 Define Safety Requirements: Define the safety factors including equipment/system design features, performance specifications and training that reduces the potential for human or machine errors or failures that cause injury or death within the constraints of operational effectiveness, time and cost throughout the equipment/system life cycle.

2.11 Define Human Engineering Requirements: Define the requirements the system must satisfy to adequately support the human operators and maintainers. Examples include supporting the cognitive, motor, and visual activities of the humans. Define the requirements the system must satisfy to adequately support the jobs and tasks that the human operators and maintainers will are expected to perform. These requirements include but are not limited to interface guidelines and requirements, operator and maintainer duty cycle requirements, and overall design of the set of tasks assigned to individual operators or maintainers. Job/task requirements also include the support of situation awareness, prediction of future system states or performance, and cognitive support such as that necessary for human takeover for automation failure.

2.12 Develop Manpower Guidelines: Estimate the limitations on manning of the system under design, either in total number of operators, users, and maintainers or by KSAs (knowledge, skills, and abilities). Examples include the definition of target manning levels such as 95 sailors or a 2-to-1 manning reduction over similar predecessor systems.

2.13 Develop Personnel Guidelines: Estimate the limitations on personnel for the users and maintainers of the system under design in terms of career pipeline, recruiting ability, personnel management, etc.

2.14 Develop Training Guidelines: Estimate the limitations on training for the users and maintainers of the system under design. Training will be limited by factors of cost, time, and personnel availability. The degree of training required will be determined by the difference in the capabilities extant in the current and projected populations and the capabilities required of the users and maintainers of the system. Capabilities that will not be available in the population or that may not be recruited from the population through screening and selection will have to be trained or otherwise developed. Capability development includes both formal and informal training programs, embedded training, and development of capabilities through previous experience and job assignments of operators and maintainers.

2.15 Develop Safety Guidelines: Provide guidance for system development to ensure that safety factors are taken into consideration early in the design process.

2.16 Develop Human Engineering Guidelines: Provide guidance for system development to ensure that humans are adequately engineered in the system. This includes descriptions of human performance principles, models, measurements and techniques.

2.17 Refine Top-Level System Functions: Refine or define to greater detail the system functions identified in the Mission Analysis. Functions may be changed due to information uncovered in previous steps of the Requirements Analysis process.

2.18 Analyze Feasibility & Internal Compatibility of System Requirements: Examine the system requirements (including mission requirements, human requirements, and job/task requirements) for discrepancies or conflicts within the requirements themselves and for variances with respect to established system characteristics such as infrastructure, interfaces with other systems, and user characteristics. Examine the system requirements for estimates of feasibility.

2.16 Define Human Requirements Baseline: Establish the baseline system requirements that ensure human capabilities and limitations that directly contribute to, or constrain, total system performance are accounted for.

3.0 – Function Analysis

DEFINITION: Define the system's functional architecture in terms of the operations/events that must be performed in order to meet the mission goals of the system. This proceeds in a top-down hierarchical nature and is independent of allocation to hardware, software, or humans. The goal of the function analysis is to assist in defining and allocating functions to the human that are best suited to their capabilities and limitations.

3.1 Translate System Requirements into Functional Architecture: Translate the defined system requirements into system functions and requirements attached to those functions.

3.2 Reconcile System Functions with Functional Requirements: Compare the functions translated from system requirements with those functions defined during Requirements Analysis. Resolve discrepancies and differences between the two.

3.3 Partition System Functions into Lower Level Functions: Partition the functions into subfunctions of greater detail. Create alternate decompositions of functions for later comparison.

3.4 Identify Information Flow: Identify the flow of information between functions required for decisions and function initiation or completion. Also identify flow of information across defined system boundaries.

3.5 Identify Functional Flow and Relationships: Identify ordering of functions, including but not limited to identification of functions dependent upon the status of other functions or external events for initiation/continuation/completion.

3.6 Identify Priority of Functions: Identify the priority and relative importance of functions in relation to one another.

3.7 Identify Duration of Functions: Estimate the time required for execution of functions and the minimum/maximum/mean times defined in the system requirements. Time limits for the functions may also be estimated. Time intervals may be driven or defined by events external to the system.

3.8 Identify Frequency of Functions: Identify the frequency or recurrence of the functions. Both planned repetition and repetition due to failure to complete the function properly should be included.

3.9 Identify Probability of Completion / Accuracy of Functions: Estimate the probability of completion or required accuracy of functions. Probabilities and accuracies may be defined as maximums, minimums, or means and may be defined from system requirements or from events external to the system. Identify or estimate the effects of failure to properly execute functions.

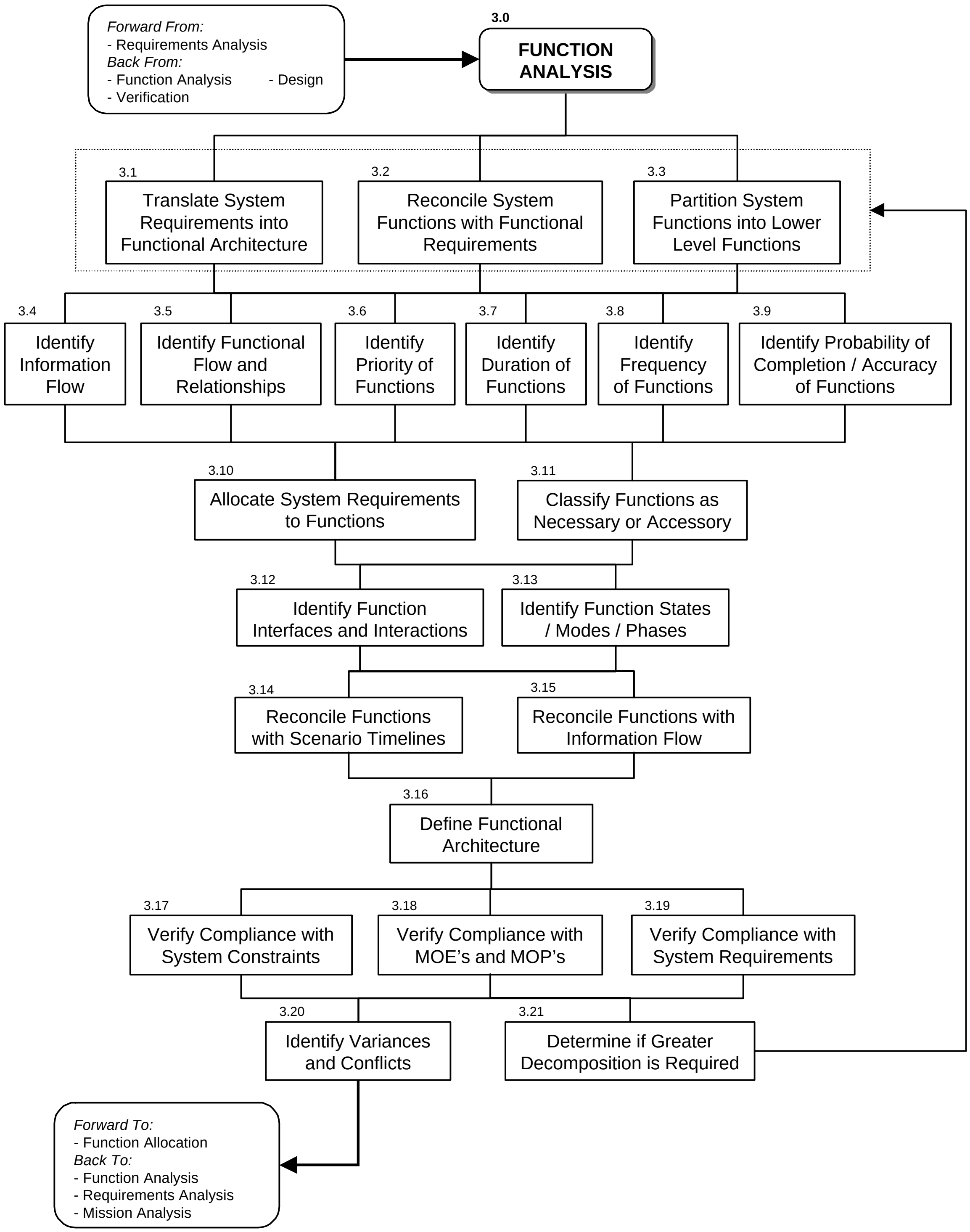

Figure 5. Function Analysis Process Diagram.

3.10 Allocate System Requirements to Functions: Allocate the system requirements to defined functions or subfunctions.

3.11 Classify Functions as Necessary or Accessory: Classify the functions within the functional architecture as necessary (or mission-critical) or accessory (or non-mission-critical). Allocation of mission-critical functions will take precedence over non-mission-critical functions.

3.12 Identify Function Interfaces and Interactions: Define the interfaces and interactions between defined functions, including inputs and outputs.

3.13 Identify Function States / Modes / Phases: Identify differences in functions across system performance and through the mission and life-cycle.

3.14 Reconcile Functions with Scenario Timelines: Determine whether or not the defined functions address all phases and events of the mission scenarios identified or created during mission analysis. Adapt or add to the functions to address deficiencies.

3.15 Reconcile Functions with Information Flow: Determine whether or not the defined functions are compatible with the defined flow of information. Adapt the functions or redefine the flow of information to address deficiencies.

3.16 Define Functional Architecture: Define the network of functions required to meet the mission needs / objective. Requirements are allocated as feasible to functions and subfunctions, but functions and subfunctions are not allocated to humans or equipment.

3.17 Verify Compliance with System Constraints: Determine whether or not the functional architecture is capable of operating within established constraints.

3.18 Verify Compliance with MOEs and MOPs: Determine whether or not the functional architecture satisfies stated measures of effectiveness and performance.

3.19 Verify Compliance with System Requirements: Determine whether or not the functional architecture is complete and satisfies current system requirements, including mission, human, and job/task requirements.

3.20 Identify Variances and Conflicts: Resolve differences in the unallocated functional architecture and system or function requirements through changing the architecture or revising the requirements.

3.21 Determine if Greater Decomposition is Required: Determine whether or not greater decomposition of functions is required before allocation of functions. If greater decomposition is not possible (or desired), begin the process of allocation of functions. Otherwise continue to define the functions and subfunctions in greater detail.

4.0 – Function Allocation

DEFINITION: Distribute the defined functions between available resources (humans, hardware, software or combinations). The allocation of some functions will be mandatory and predetermined by constraints established in the Mission Analysis or Requirements Analysis stages of design. Allocation should also be determined by comparison of performance between humans, hardware, and software; cost factors; and affective and cognitive support for the operators. Allocation decisions should be made so as to maximize total system performance and effectiveness. Allocation of a function may require redefinition of its component subfunctions. Function allocation will also be guided by what pieces of information and decisions are required to initiate, sustain, and otherwise support the functions. The designer must determine how decisions affect or alter the system performance of the system itself. Allocation may be done in static terms or it may be dynamic, with functions changing their allocation at different stages of the system. The system must be defined in terms of component functions, tasks, and subtasks, including the flow of information and the allocation of the functions, tasks, and subtasks to individual system components.

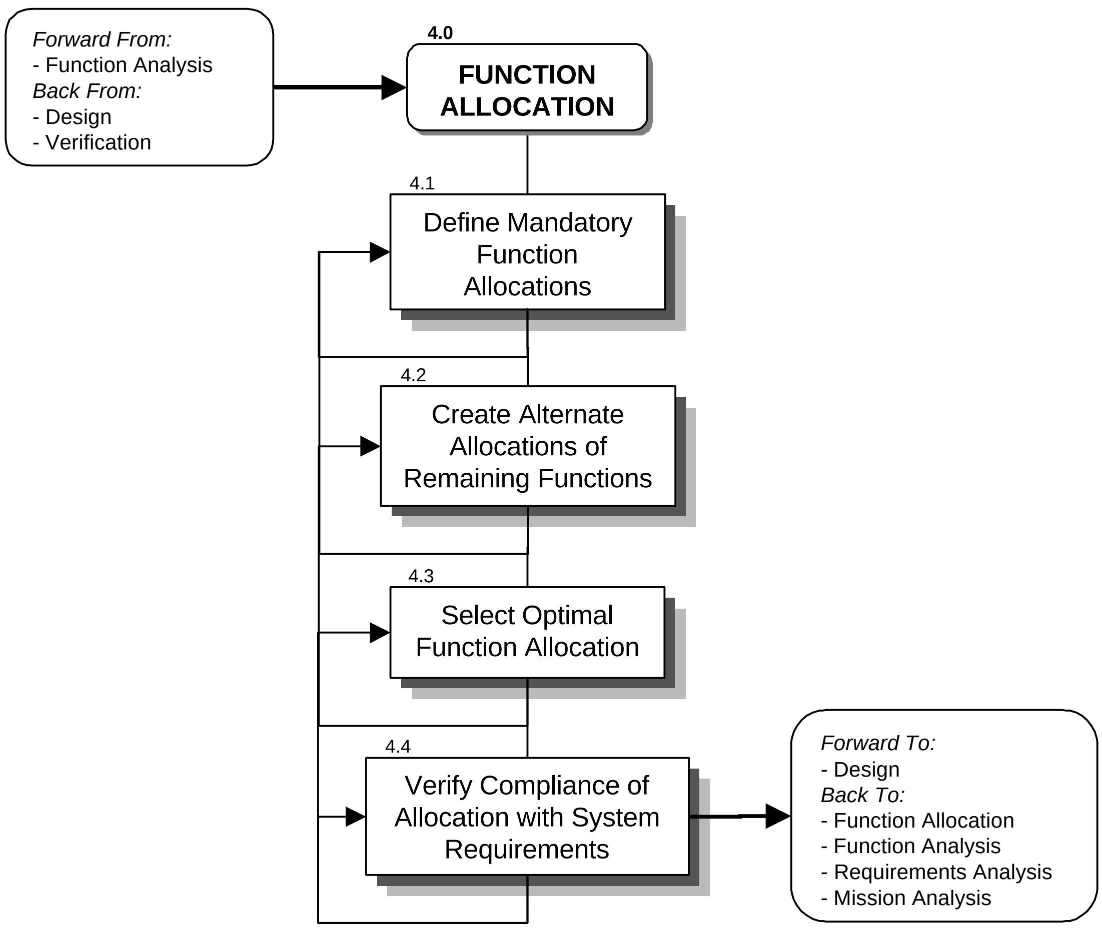

Figure 6. Function Allocation Process Diagram.

4.1 DEFINE MANDATORY FUNCTION ALLOCATIONS

The first functions and decisions to be allocated must be those having specific allocations mandated by system requirements, the Human Role Strategy, or other factors. The Human Role Strategy will require that some functions or decisions be performed or made by humans within the system. Some functions or decisions will be required to be performed or made by hardware or software components of the system or by humans with the assistance of other system components in order to meet system requirements. The allocation of these functions and decisions may then logically require that other functions or decisions be allocated to a specific portion of the system.

4.1.1 Identify requirements of Human Role Strategy: Analyze the Human Role Strategy to determine the impact on both function and decision allocation.

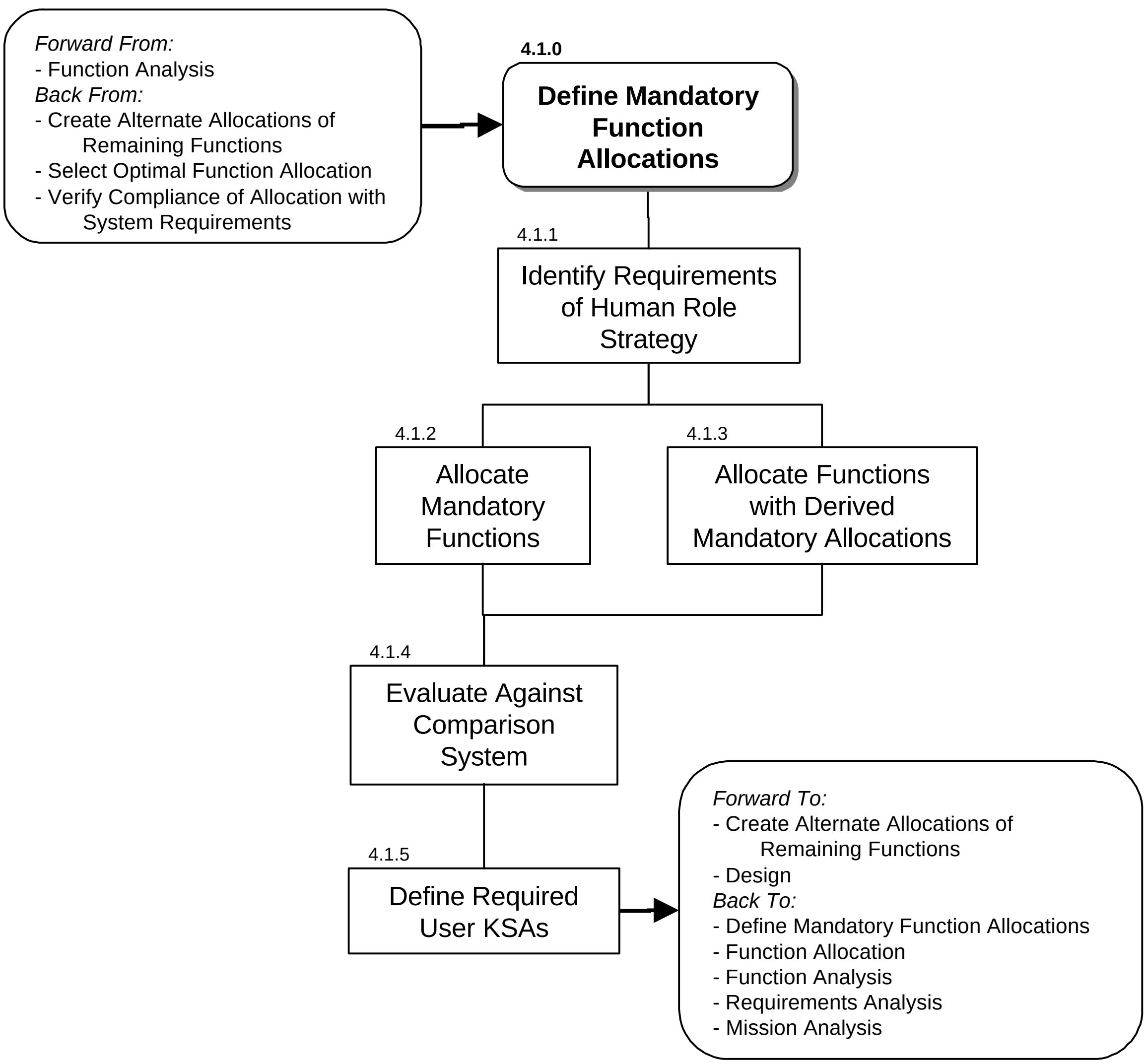

Figure 7. Define Mandatory Function Allocations Process Diagram.

4.1.2 Allocate Mandatory Functions: Based on the Human Role Strategy and other identified mandatory allocation requirements, allocate functions and decisions to human, equipment, or combinations to account for mandatory function and decision allocations.

4.1.3 Allocate Functions with Derived Mandatory Allocations: Determine which functions or decisions are now required to be allocated to a particular resource due to the previously allocated functions and decisions.

4.1.4 Evaluate Against Comparison System: Compare the current allocation of functions to the allocation within current similar systems or the Baseline Comparison System. Use the comparison to estimate the performance and other characteristics of the current allocation.
Source: [7], Sec. 1.3.4 “Reverse engineer the BCS function allocation”

4.1.5 Define Required User KSAs: Given the mandatory allocations, determine the KSAs (knowledge, skills, and abilities) that will be required of the humans that will be a part of the system.

4.2 CREATE ALTERNATE ALLOCATIONS OF REMAINING FUNCTIONS
Identify potential allocations for functions not yet allocated. Begin by assessing the capabilities and limitations of hardware and software technology as well as humans. Allocations may be made to hardware, software, humans, or combinations. Allocation may be static or dynamic, changing with operational conditions, workloads, or mission priorities. Allocation of mission-critical functions during the primary mission phase should take priority, followed by other primary mission functions and functions from other mission phases. Allocation options should be made based on component and system performance and a variety of other criteria.

4.2.1 Identify Operator & Maintainer Capabilities and Limitations: Identify the characteristics, frequency, and distribution of the capabilities and limitations of the potential operator, user, and maintainer populations. With respect to surface combatant design, manpower must be assessed by rating (or similar format) and rating attributes must be adaptable to reflect future populations.

4.2.2 Identify Technology Capabilities and Limitations: Identify the potential for hardware and software to perform the system’s functions. The ability of the technology to perform, availability, cost, and compatibility are among the factors that must be addressed. Potential obstacles to technology insertion and acceptance such as confidence in technology or information and compatibility with operator and maintainer expectations, training, or experience must be identified.

4.2.3 Identify Potential Allocations of Each Function: Develop alternate options and strategies for the allocation of functions. Include assessment of the capability of future hardware and software technology to assume roles that could only be allocated to humans previously.

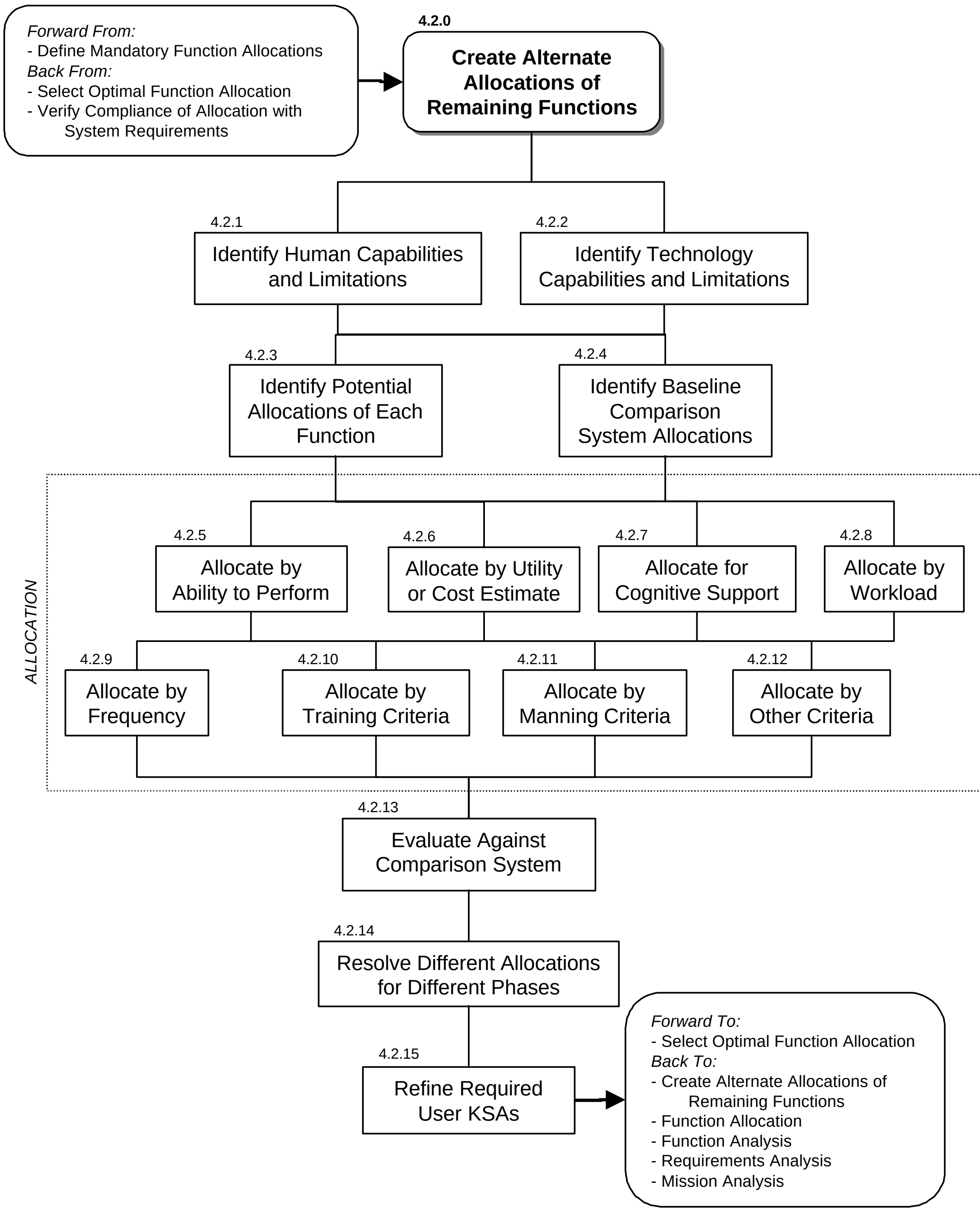

Figure 8. Create Alternate Allocations of Remaining Functions Process Diagram.

4.2.4 Identify Comparison System Allocations: Identify how functions within the current system's functional architecture have been allocated in past systems, especially in any system designated as a Baseline Comparison System. Assess how technological advances since the comparison system was designed or constructed could affect the possibilities for current or future function allocation. Assess the performance of the comparison system with respect to its allocations, especially with respect to allocations that failed to meet system requirements or expectations.

4.2.5 Allocate By Ability to Perform: Determine allocation of functions based on the performance level for humans or machines as performers of the intended functions.

4.2.6 Allocate by Utility or Cost Estimate: Determine allocation of functions based on minimizing cost. Cost of training and supporting a human or humans is compared to the cost of developing, installing, and maintaining the equipment required to perform the functions.

4.2.7 Allocate for Cognitive Support: Determine allocation of functions based on affective needs of the operators (emotional needs, need to feel in control and secure) and for cognitive support. Cognitive issues include the need for information for later decisions, the need to maintain situation awareness and an appropriate mental model of the situation, and the need to maintain the ability of the human to resume control of automation in case of equipment failure.

4.2.8 Allocate by Workload: Determine the allocation of functions based on the workload placed on humans in the system due to the allocation of the functions.

4.2.9 Allocate by Frequency: Determine the allocation of functions based on the rate of occurrence of the functions.

4.2.10 Allocate by Training Criteria: Determine allocation of functions based on the training requirements associated with the potential allocations. Training is minimized by requiring operator and maintainer capabilities that are similar to the capabilities currently available and projected to be available among the potential operators and maintainers.

4.2.11 Allocate by Manning Criteria: Determine allocation of functions based on the manning requirements associated with the potential allocations. Manning requirements include total number of operators and maintainers as well as skill and experience levels of the operators and maintainers.

4.2.12 Allocate by Other Criteria: Determine allocation of functions based on other criteria such as safety issues, criticality, feasibility, etc.

4.2.13 Evaluate Against Comparison System: Compare the current allocation of functions to the allocation within current similar systems or the comparison system. Use the comparison to estimate the performance and other characteristics of the current allocation.

4.2.14 Resolve Different Allocations for Different Phases: Resolve differing optimum allocation for different mission phases through either overall best static allocation, through dynamic reallocation, or through allocations to human/hardware/software combinations. Implementation of dynamic allocation or reallocation will require addition of the system functionality necessary to switching allocation of the functions.

4.2.15 Refine Required User KSAs: Given the current functional architecture and allocation decisions, refine the previous estimates of the KSAs (knowledge, skills, and abilities) that will be required of the system operators and maintainers.

4.3 Select Optimal Function Allocation

Based on a qualitative comparison of system design factors (SDFs), select an optimal allocation of functions from the candidate allocations.

4.3.1 Select SDF Weighting Factors: Determine the relative importance and select weights for the system design weighting factors.

4.3.2 Compare Risk / Feasibility: Compare allocation alternatives with respect to the risk and feasibility of the design.

4.3.3 Compare Time Required: Compare allocation alternatives with respect to the time required to implement the design and for the system to perform.

4.3.4 Compare Performance: Compare allocation alternatives with respect to system or component performance.

4.3.5 Compare Manning: Compare allocation alternatives with respect to system or subsystem manning levels.

4.3.6 Compare Workload: Compare allocation alternatives with respect to individual or group workload.

4.3.7 Compare Life-Cycle Cost: Compare allocation alternatives with respect to overall life-cycle cost.

4.3.8 Compare Availability: Compare allocation alternatives with respect to system or component availability to perform mission.

4.3.8a Compare Training: Compare allocation alternatives with respect to associated life-cycle training requirements.

4.3.9 Compare Other SDFs: Compare allocation alternatives with respect to other desired design factors.

4.3.10 Tradeoff and Select Allocation: Compare the SDF estimates for different allocations and for different mission phases and stages of the life-cycle. Perform tradeoffs between the allocation and select the optimum allocation configuration.

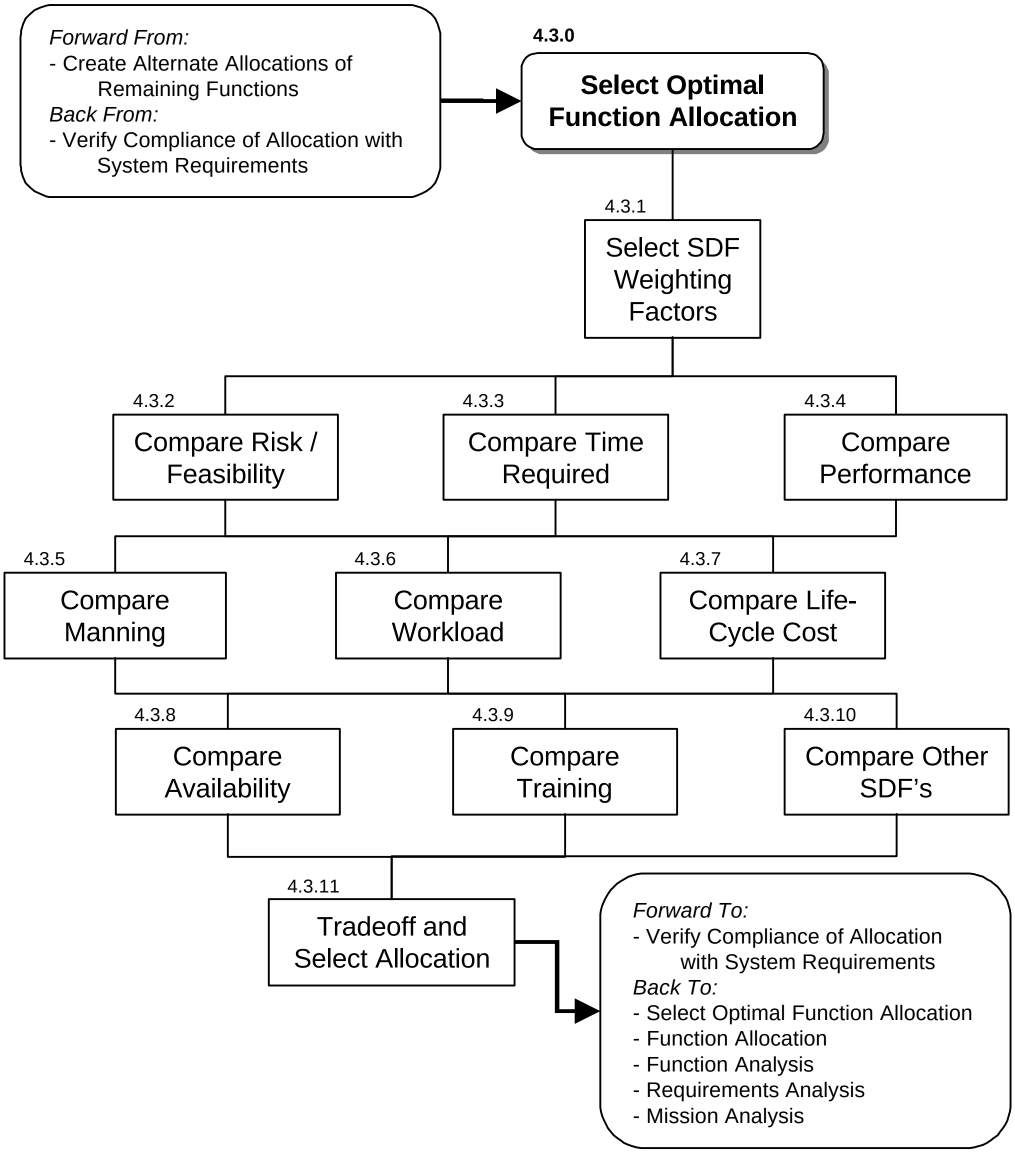

Figure 9. Select Optimal Function Allocation Process Diagram.

4.4 VERIFY ALLOCATION COMPLIANCE WITH SYSTEM REQUIREMENTS

Compare the selected allocation of functions to the system requirements, including mission requirements, human requirements, job/task requirements, and other MOEs and MOPs.

4.4.1 Estimate Risk / Feasibility: Estimate the risk and feasibility of the selected allocation.

4.4.2 Estimate Time Required: Estimate the time required to implement the design and for the system to perform given the selected allocation.

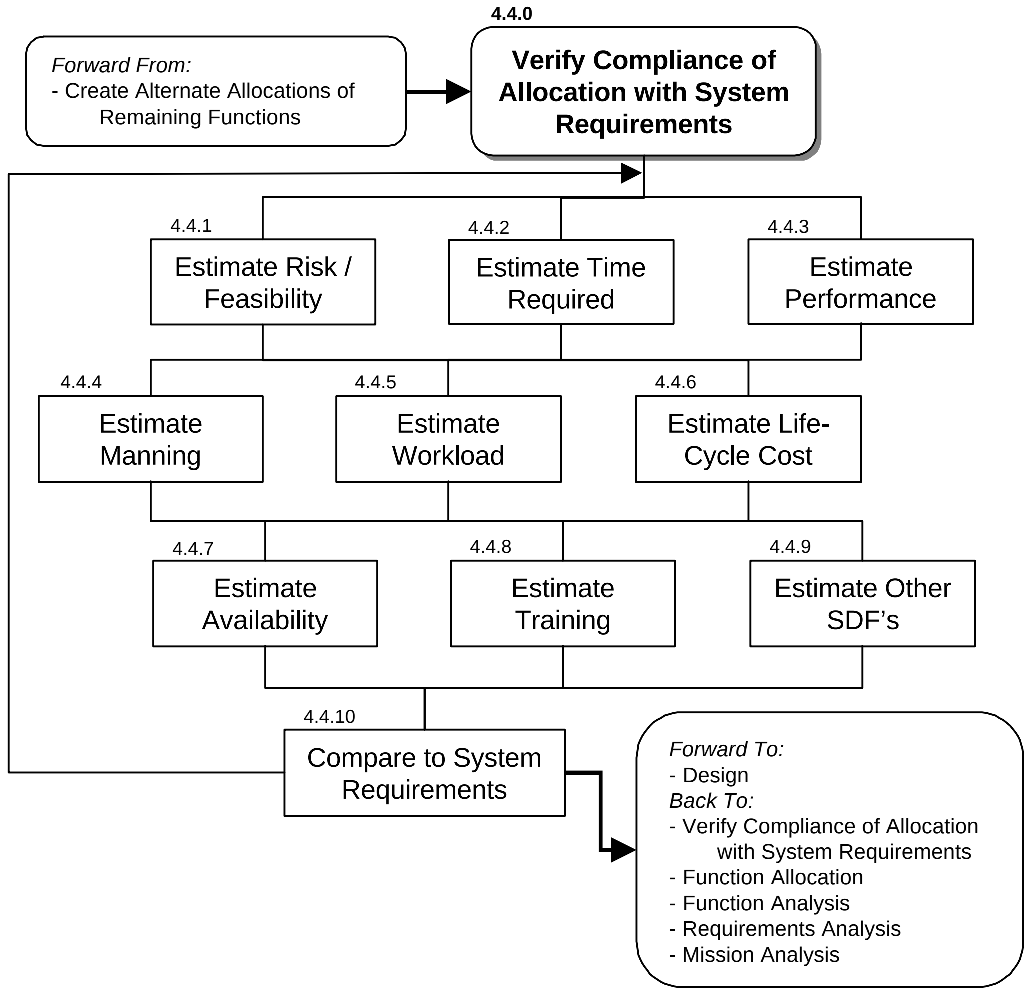

Figure 10. Verify Compliance of Selected Allocation with System Requirements Process Diagram.

4.4.3 Estimate Performance: Estimate the system or component performance given the selected allocation.

4.4.4 Estimate Manning: Estimate the system or subsystem manning levels given the selected allocation. These estimates become further inputs to the system's Manning Document.

4.4.5 Estimate Workload: Estimate individual or group workload given the selected allocation.

4.4.6 Estimate Life-Cycle Cost: Estimate overall life-cycle cost given the selected allocation. These estimates become further inputs to the system's Cost Document.

4.4.7 Estimate Availability: Estimate system or component availability to perform mission given the selected allocation.

4.3.8 Estimate Training: Estimate life-cycle training requirements given the selected allocation. These estimates become further inputs to the system's Training Plan.

4.4.9 Estimate Other SDFs: Estimate other desired design factors given the selected allocation.

4.4.10 Compare to System Requirements: Determine whether or not the current system allocation will satisfy MOEs and MOPs and other system requirements. If the current system allocation is unsatisfactory, decide whether to re-perform the allocation of functions, adapt the system requirements, or some combination.

5.0 – Design

DEFINITION: Translate the functional architecture into the information required to adequately represent the system behaviorally, graphically, etc. to enable the production and test of the system. Attention is focused on decision analysis and task design; information flow (human to computer, human to human); human workload (cognitive, physical, time); human-machine interface; anthrpometrics; etc.. Trades-off are made to ensure that the system architecture optimizes all resources and yields maximum performance.

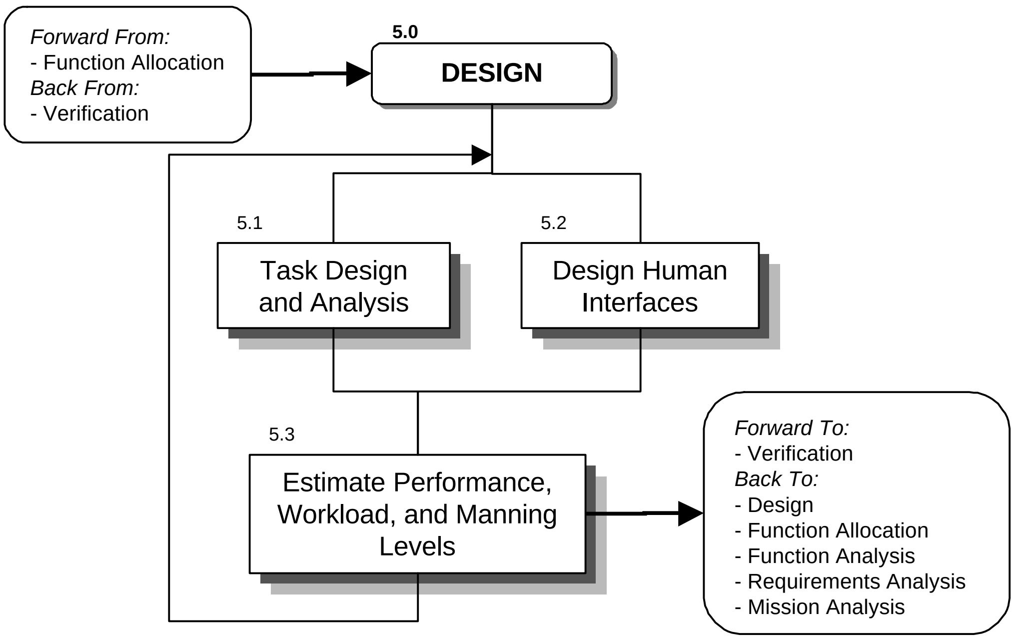

Figure 11. Design Process Diagram.

5.1 Task Design and Analysis

Based on the functions allocated to humans, develop the human tasks required to ensure successful completion of the function. Task development is based on a decision analysis approach. This produces a depiction of the task in terms of the cues to alert the human that a decision/action needs to be taken, the decisions/action to be made, the information required to support the decision, and mechanisms to implement the results of the decision/action. The critical characteristics and interactions are also articulated.

5.1.1 Identify Human Tasks: Identify the tasks that are to be carried out by human operators, users, or maintainers. Both mission and non-mission tasks (such as HCI or general human tasks) that are derived from allocations or previous design decisions are included. Physical and cognitive tasks must be included, as must tasks due to dynamic function allocation. Decisions required for task completion are articulated and the information requirements for the decisions documented.

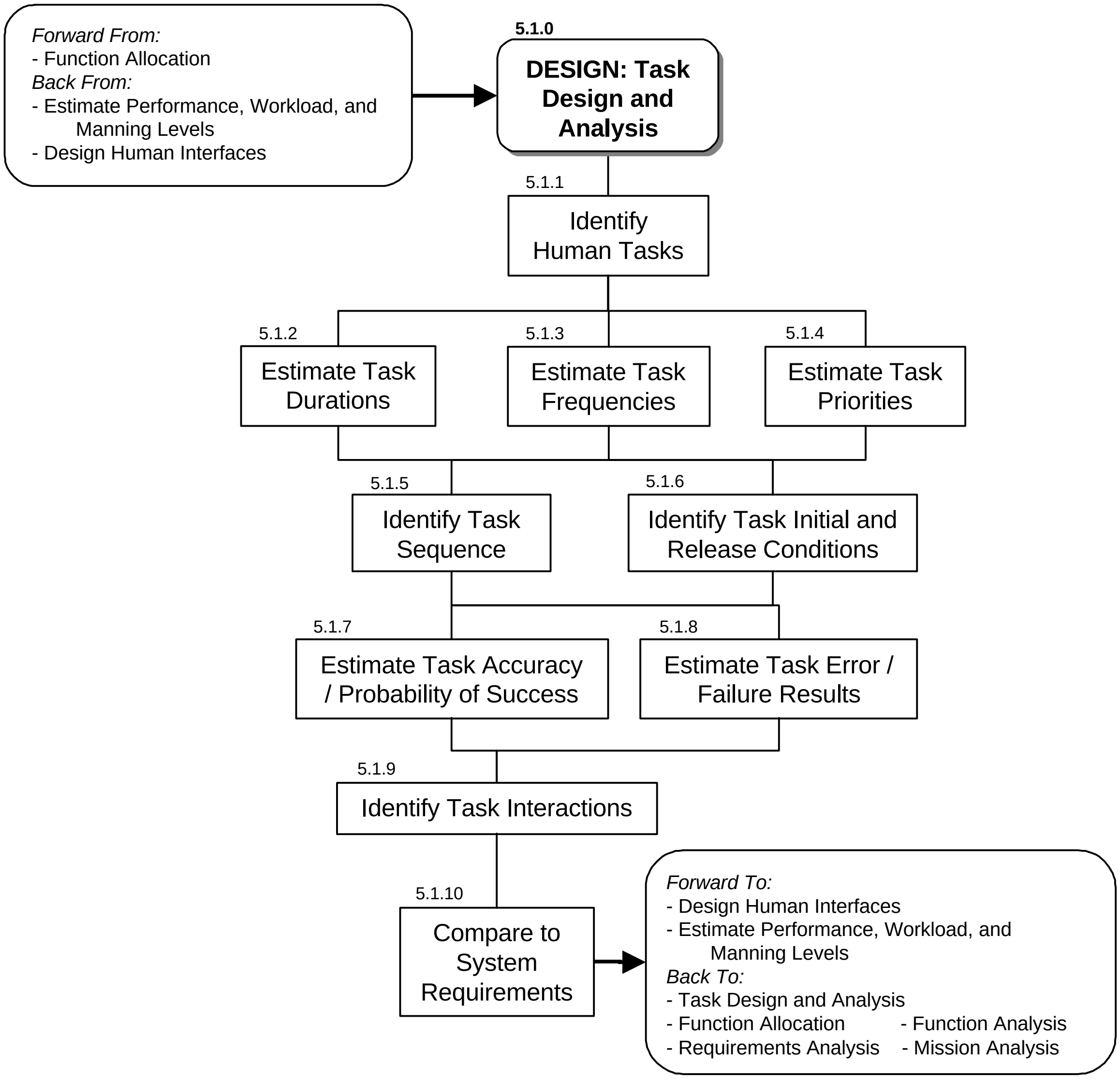

Figure 12. Task Design and Analysis Process Diagram.

5.1.2 Estimate Task Durations: Estimate the mean and distribution of the time required to perform the tasks assigned to the humans. Include estimations of worst-case durations.

5.1.3 Estimate Task Frequencies: Estimate the frequencies or rates of occurrence of the tasks to be performed by the human operators and maintainers.

5.1.4 Estimate Task Priorities: Estimate the priorities of the tasks assigned to humans with respect to the system mission and overall performance. Also estimate the priorities that the operators, users, and maintainers will give to their assigned tasks. Estimate the effects of discrepancies in the two types of priorities and ways to resolve the differences or eliminate their effects.

5.1.5 Identify Task Sequence: Identify the sequence of the tasks assigned to humans, including tasks that are to be performed simultaneously. Coordinate the sequence of human tasks with the sequence of functions assigned to equipment.

5.1.6 Identify Task Initial and Release Conditions: Identify the information, actions, and events (internal and external to the system) that are required for the human tasks to be initiated, continued, or terminated.

5.1.7 Estimate Accuracy / Probability of Success: Estimate both the accuracy of the human in performing the assigned tasks and the probability of success.

5.1.8 Estimate Task Error / Failure Results: Identify the types of errors that may be committed by human operators, users, and maintainers in carrying out their assigned tasks. Estimate the effects on the system, its components, and other functions and tasks of errors or failures to complete the tasks. Tasks for fault recovery and human take-over for automation and hardware/software take-over for human failure must be included and addressed through the remainder of the design process.

5.1.9 Identify Task Interactions: Identify interactions between tasks and between tasks and factors external to the system. Identify how the presence or absence of system inputs and outputs will alter the task flow of the operators, users, and maintainers. This includes the identification of task overlaps and wait times not previously addressed and interaction with tasks or functions allocated to non-human system components.

5.1.10 Compare to System Requirements: Compare the design of the operator and maintainer tasks to the system requirements, including mission requirements, human requirements, job/task requirements, and other MOEs and MOPs.

5.2 DESIGN HUMAN INTERFACES

Design the interfaces between humans and hardware, software, and other humans. Both physical and procedural interfaces should be considered. Develop individual and team interfaces.

5.2.1 Identify / Implement Interface Guidelines: Identify existing guidelines applicable to the information or material passed between humans and equipment or between humans. Guidelines may include, but are not limited to, short term and working memory limitations, display and control modalities, and physical or strength limitations. These guidelines include those defined in, derived from, or implied by human and job/task requirements.

5.2.2 Identify Points of Human Interfaces: Determine the points in the allocated functional architecture at which information/objects/etc. are transitioned between humans or equipment (hardware or software).

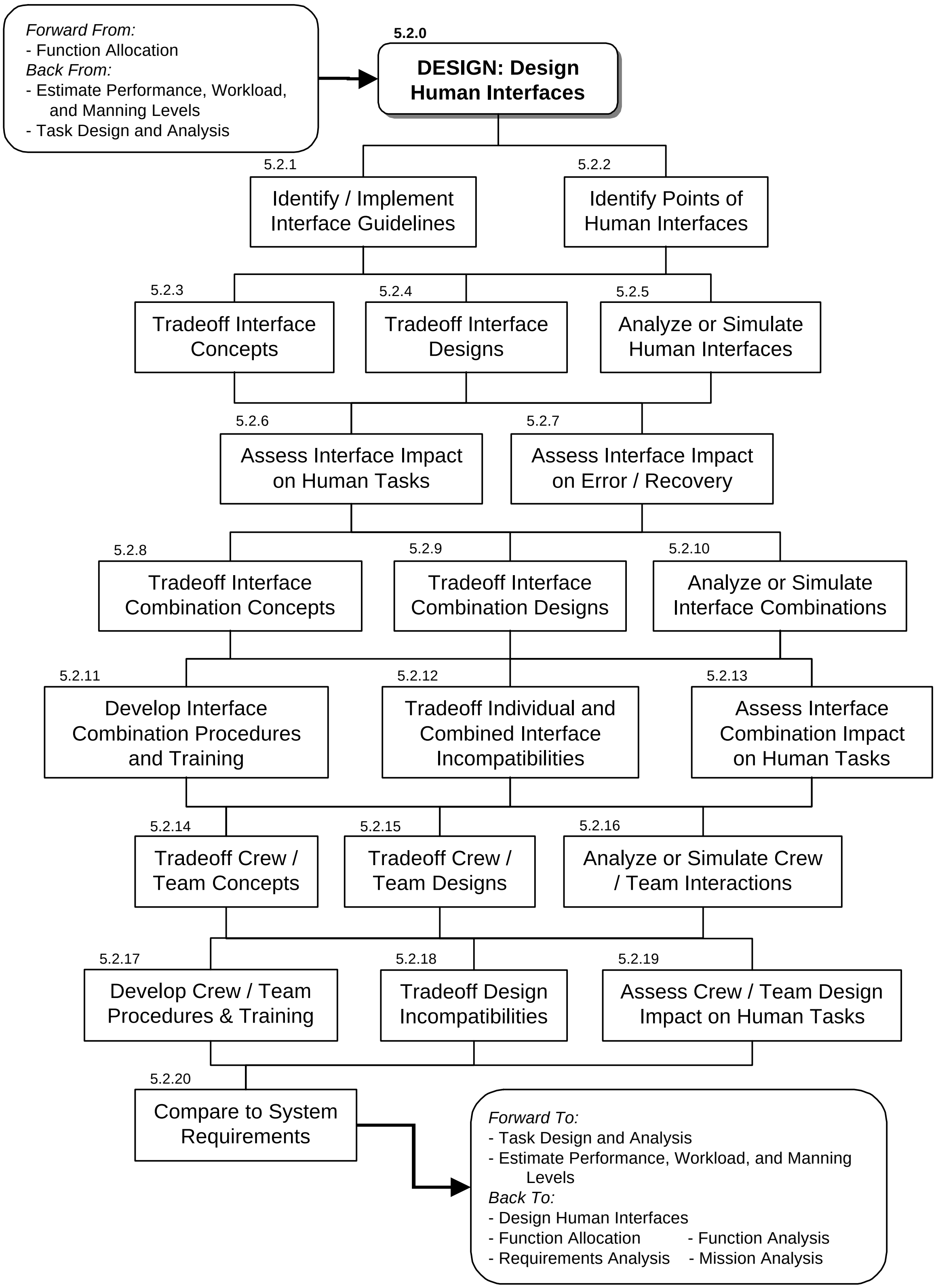

Figure 13. Design Human Interfaces Process Diagram.

5.2.3 Tradeoff Interface Concepts: Compare and select among alternate individual operator interface concepts. The interface at this point is defined in general terms such as input and output modalities, graphics as opposed to text, etc. This tradeoff will permit the selection of candidate input and output modalities, devices, and procedures.

5.2.4 Tradeoff Interface Designs: Compare and select among alternate individual operator interface designs developed from the selected interface concepts. This design includes information representation, as well as modality specification.

5.2.5 Analyze or Simulate Human Interfaces: Simulate and test the selected individual human interface design(s). Simulations may be static or dynamic, part or whole task, open or closed loop, and may include a human operator, without an operator, or with an operator model.

5.2.6 Assess Interface Impact on Human Tasks: Determine how the selected interface affects the task performance of the human. Identify the non-mission tasks (such as HCI tasks) that the interface has added to original task set assigned to the human. Assess the compliance of these tasks with both human and job/task requirements.

5.2.7 Assess Interface on Error/Recovery: Assess the effect error has on task performance. Determine how the selected interface responds to predicted human error and how well it supports task recovery.

5.2.8 Tradeoff Interface Combination Concepts: Compare and select among alternate concepts for human interface combinations or workstations and work environments. Interference between tasks and individual interface components should be identified and resolved.

5.2.9 Tradeoff Interface Combination Designs: Compare and select among alternate human interface combinations or workstations and work environment developed from the selected concepts. Designs should be selected to promote compatibility and eliminate confusion and discrepancy between interfaces of individual components.

5.2.10 Analyze or Simulate Interface Combinations: Analyze or simulate and test the selected individual operator interface combinations or workstation and work environment designs. Simulations may be static or dynamic, part or whole task, open or closed loop, and may include a human operator, without an operator, or with an operator model.

5.2.11 Develop Interface Combination Procedures and Training: Begin to develop the procedures and instructions for operator, users, and maintainer training. When possible, change the interfaces, interface combinations, or work environments to facilitate embedded training or to reduce the amount and degree of training or KSAs required to perform the assigned tasks.

5.2.12 Tradeoff Individual and Combined Interface Incompatibilities: Resolve incompatibilities between individual interface components and the combinations of interfaces and work environments.

5.2.13 Assess Interface Combination Impact on Human Tasks: Determine how the selected interface combination affects the tasks of the human. Identify the non-mission tasks (such as HCI tasks) that the interface has added to the tasks assigned to the human. Assess the compliance of these tasks with both human and job/task requirements.

5.2.14 Tradeoff Crew / Team Concepts: Compare and select among alternate concepts for team interactions. Interference between tasks and individuals within the team and team inputs and outputs should be identified and resolved.

5.2.15 Tradeoff Crew / Team Designs: Compare and select among specific designs for teams.

5.2.16 Analyze or Simulate Crew / Team Interactions: Analyze or simulate and test the selected designs for teams. Simulations may be static or dynamic, part or whole task, open or closed loop, and may include a human operator, without an operator, or with an operator model.

5.2.17 Develop Crew / Team Procedures and Training: Begin to develop the procedures and instructions for team training. When possible, change the team designs to facilitate embedded training and to reduce the amount and degree of training required (through means such as consistency of interface combinations across an individual's roles) as well as the knowledge, skills, and abilities required to perform the assigned tasks.

5.2.18 Tradeoff Design Incompatibilities: Resolve incompatibilities between team designs, interfaces and interface combinations, work environments, and individual interface components.

5.2.19 Assess Crew / Team Design Impact on Operator Tasks: Determine how the selected team design affects the tasks of the human. Identify the non-mission tasks (such as HCI tasks) that have been added to the tasks assigned to the human. Assess the compliance of these tasks with both human and job/task requirements.

5.2.20 Compare to System Requirements: Compare the design of the interfaces and team designs to the system requirements, including mission requirements, human requirements, job/task requirements, and other MOEs and MOPs.

5.3 Estimate Performance, Workload, and Manning Levels

Estimate the physical (perceptual, psychomotor, physiological, etc.) and cognitive workload levels of individuals and teams within the system. Define workload stressors and their effects on human performance, operator coping strategies, and the effects of task neglect/delay. Workload and the resultant manning and training requirements are to be optimized to meet required performance levels.

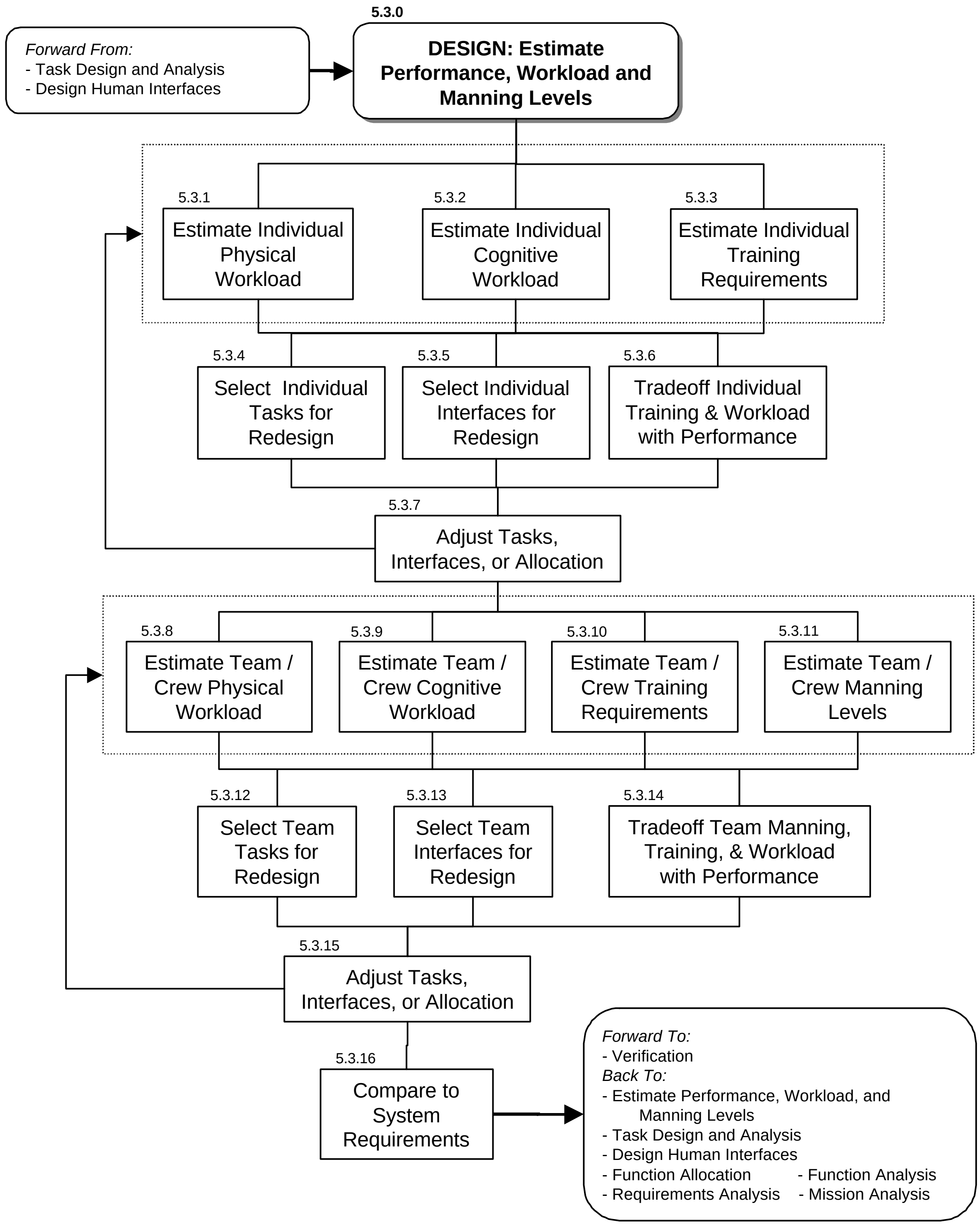

Figure 14. Evaluate Performance, Workload, and Manning Process Diagram.

5.3.1 Estimate Individual Physical Workload: Given the designed tasks allocated to each human, estimate the physical workload demands of the tasks. Identify acceptable workload limits for different mission phases, accounting for time and environmental effects.

5.3.2 Estimate Individual Cognitive Workload: Given the defined tasks allocated to each human, estimate the cognitive workload demands of the tasks. Identify acceptable workload limits for different mission phases, accounting for time and environmental effects.

5.3.3 Estimate Individual Training Requirements: Given the defined tasks allocated to each human, estimate the degree of training required to develop the necessary capabilities for successful performance.

5.3.4 Select Individual Tasks for Redesign: Identify mission phases or human roles and tasks that produce unacceptably high (or low) levels of workload.

5.3.5 Select Individual Interfaces for Redesign: Identify interfaces that produce unacceptably high (or low) levels of workload.

5.3.6 Tradeoff Individual Training & Workload with Performance: Assess the effects of high workload on human performance. Determine whether or not performance levels will be acceptable at these levels of workload. Assess the training required and its associated cost.

5.3.7 Adjust Tasks, Interfaces, or Allocation: Change the tasks and functions that produce unacceptable levels of workload through task automation, consolidation, elimination, simplification, or allocation to other humans.

5.3.8 Estimate Team / Crew Physical Workload: Given the defined tasks allocated to teams, estimate the physical workload demands on each individual and the group as a whole. Identify acceptable workload limits for different mission phases, accounting for time and environmental effects.

5.3.9 Estimate Team / Crew Cognitive Workload: Given the defined tasks allocated to teams, estimate the cognitive workload demands on each individual and the group as a whole. Identify acceptable workload limits for different mission phases, accounting for time and environmental effects.

5.3.10 Estimate Team / Crew Training Requirements: Given the defined tasks allocated to teams, estimate the degree of training required to develop the necessary capabilities for successful performance.

5.3.11 Estimate Team / Crew Manning Levels: Given the defined tasks allocated to teams, estimate the overall manning levels required. Manning levels should be compared across different mission phases and life-cycle stages. Manning level definition should include both the total number of operators and maintainers as well as their skill and experience levels.

5.3.12 Select Team Tasks for Redesign: Identify mission phases, human roles and tasks, or combinations of human roles and tasks that produce unacceptably high (or low) levels of workload.

5.3.13 Select Team Interfaces for Redesign: Identify team interfaces that produce unacceptably high (or low) levels of workload.

5.3.14 Tradeoff Team Manning, Training, & Workload with Performance: Assess the effects of high workload on team performance. Determine whether or not performance levels are acceptable at these levels of workload.

5.3.15 Adjust Tasks or Allocation: Change the tasks and functions that produce unacceptable levels of workload through task automation, consolidation, elimination, simplification, or allocation to other human within the team or to other teams.

5.3.16 Compare to System Requirements: Compare the design of team tasks to the system requirements, including mission requirements, human requirements, job/task requirements, and other MOEs and MOPs.

6.0 – Verification

DEFINITION: Assess the potential performance of the system with respect to its ability to achieve its required levels of operation (MOEs, MOPs). Verification, assessment and validation may be carried out either during conceptual stages using analytical or executable system models or after a physical prototype or mock-up has been constructed using human-in-the-loop simulations. Testing and evaluation of some system components may be concurrent with design of other components. Testing and evaluation is performed within the context of design, not production. If the system under design is unable to achieve the required levels of performance and operation, then either the requirements must be altered or the design must be improved through re-allocation of functions or selection of an alternate design.

6.1 Plan Verification: Plan tests, simulations, and demonstrations to determine system compliance with human engineering guidelines and with system requirements. Plan also for tests and evaluations that will occur once the system is deployed.

6.2 Compare to Measures of Effectiveness: Verify that the design adequately meets the stated measures of effectiveness.

6.3 Compare to Measures of Performance: Verify that the design adequately meets the stated measures of performance.

6.4 Compare to Infrastructure Requirements: Verify that the design adequately meets the stated infrastructure requirements. Verify that the supporting infrastructure that is assumed to be available to the system will in fact be available.

6.5 Compare to Manning Requirements: Verify that the design adequately meets the stated manning requirements.

6.6 Compare to Personnel Requirements: Verify that the design adequately meets the stated personnel requirements.

6.7 Compare to Training Requirements: Verify that the design adequately meets the stated training requirements.

6.8 Compare to Safety Requirements: Verify that the design adequately meets the stated safety requirements.

6.9 Compare to Human Engineering Requirements: Verify that the design adequately meets the stated human engineering requirements.

6.10 Verify Manning Structure: Verify that the design is adequately supported with the designed manning structure.

6.11 Verify Task Structure: Verify that the design is adequately supported with the designed structure of tasks assigned to humans.

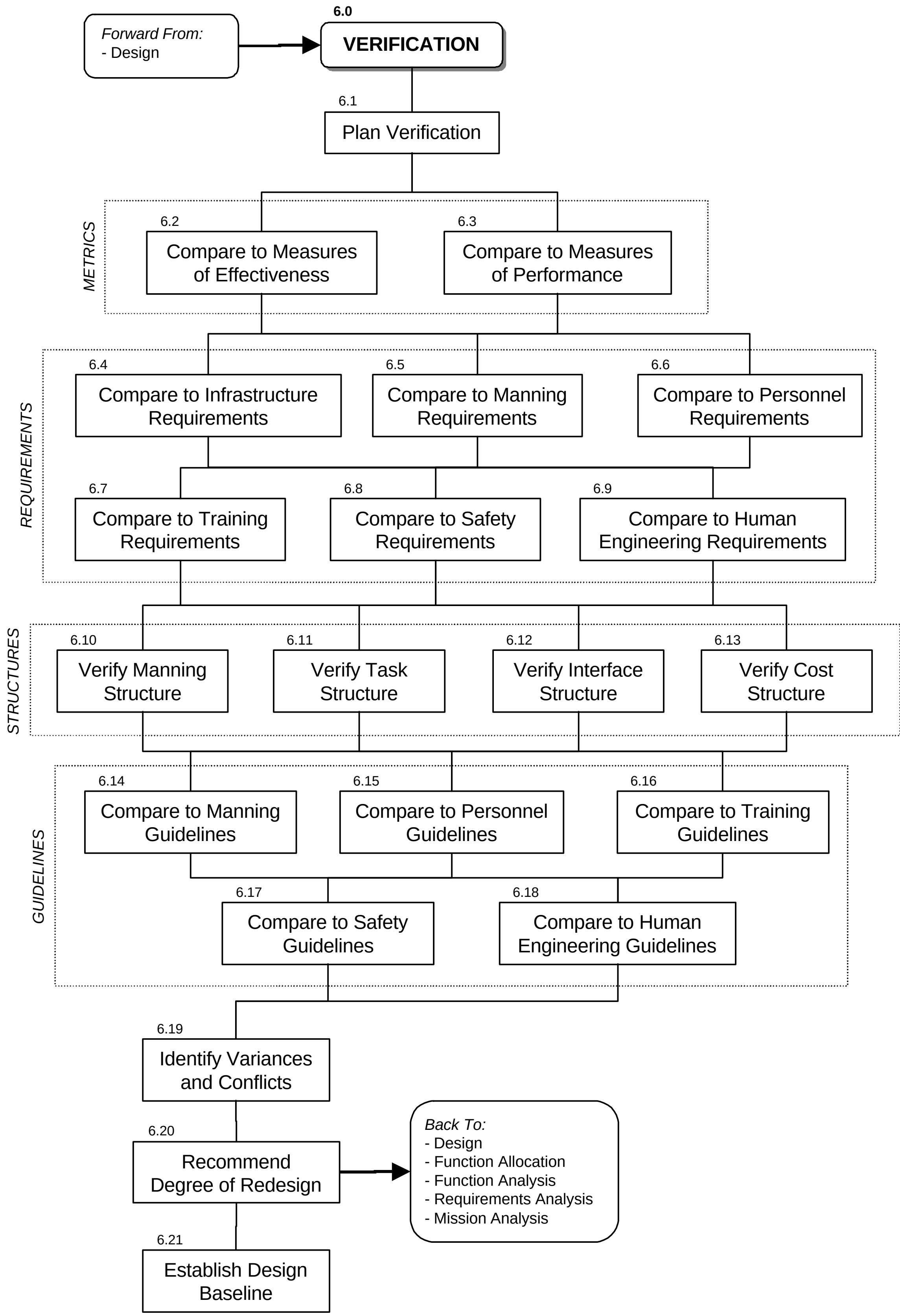

Figure 15. Verification Process Diagram.

6.12 Verify Interface Structure: Verify that the design is adequately supported with the designed interface structure. Interfaces between humans and other components of the system (including other humans) and between the system and other systems are included.

6.13 Verify Cost Structure: Verify that the design is adequately supported with the designed cost structure.

6.14 Compare to Manning Guideline: Verify that the design does not conflict with the established manning guidance.

6.15 Compare to Personnel Guideline: Verify that the design does not conflict with the established personnel guidance.

6.16 Compare to Training Guideline: Verify that the design does not conflict with the established training guidance.

6.17 Compare to Safety Guideline: Verify that the design does not conflict with the established safety guidance.

6.18 Compare to Human Engineering Guideline: Verify that the does not conflict with the established human engineering guidance.

6.19 Identify Variances and Conflicts: Based on the above comparisons and verifications, identify where the design is in conflict or deviates from above criteria.

6.20 Recommend Degree of Redesign: Compare the benefits and costs of potential redesign strategies along with risks of not performing the redesign and recommend the appropriate course of action.

6.21 Establish Design Baseline: Articulate the design such that it can be archived as the baseline and establish configuration management procedures to ensure design changes are documented and traceable.

Definitions

Allocation: The distribution, allotment, or apportionment of a function or decision to lower level components of a system (including hardware, software, or humans). Allocation may be made entirely to one of these three components, to some combination that will be decomposed at an even lower level, or to dynamic allocation where the executing components may change during system operation.

Comparison System (CS): An existing system with a mission, purpose, or process similar to that of the system under design, selected to guide the development of the current system. The CS can provide information about previously effective or ineffective function allocation options, manning and/or workload drivers, and other lessons learned. Advances in technology or other system facilitators since the design of the CS must be identified and considered.

Constraint: A limitation or implied requirement which limits the design solution or implementation of the systems engineering process, is not changeable by the performing activity, and is generally non-allocable.

Detailed Physical Architecture: A description of the system in terms of the specific pieces and elements of hardware, software, humans, and combinations that will work together to carry out the system's required functions thoughout the system life-cycle.

Functional Architecture: An arrangement of functions and their subfunctions and functional interfaces (internal and external) which defines the execution sequencing, conditions for control or data-flow, and the performance requirements to satisfy the requirements baseline.

General Physical Architecture: A description of the functions the system will perform, allocated to hardware, software, humans, and combinations. Allocation is in general terms, and the generic physical architecture will be used to build the detailed physical architecture.

Human Role Strategy (HRS): Plan or strategy for human involvement in a system that will be used to guide function allocation and thereby define the role of the human(s) within the system.

Measure of Effectiveness: A metric by which a customer will measure satisfaction with products produced by the technical effort.

Measure of Performance: A performance measure that provides design requirements that are necessary to satisfy an MOE. There are generally several measures of performance for each measure of effectiveness.

Performance Shaping Factor: An external variable such as environmental conditions, time of day, or state of mind that can effect or otherwise shape the performance of humans within a system.

Physical Architecture (generic, detailed, or validated): An allocated arrangement of physical elements which provides the design solution for a consumer product or life-cycle process intended to satisfy the requirements of the functional architecture and the requirements baseline.

Requirement: A statement which identifies a product or process capability, physical characteristic which is unambiguous and quantitative whenever possible.

Requirements Baseline: The composite set of operational, functional and physical requirements that serve to guide development and management decision processes.

System Design Factor (SDF): A metric or variable used to measure the quality of a candidate design of the system.

Validated Physical Architecture: A validated description of the total system in terms of the specific pieces and elements of hardware, software, and humans that will work together to carry out the system's required functions throughout the system life-cycle. The system has been validated in that it has been tested as components and as a total system and found to satisfy system requirements and be ready for production.

Workload: A measure of the demand placed upon the internal resources of a human. Workload is affected by both the external demands on the human as well as the resources available. Workload may be measured or estimated in cognitive or physical (perceptual, physiological, psychomotor, etc.) terms, measure through subjective means, or inferred through level of performance. Workload also refers to the amount of time required to successfully complete a task.